

ON A NEW SYSTEM
OF
CONNECTING THE UNDERGROUND
MINE-SURVEY
WITH THAT OF THE SURFACE.

INAUGURAL DISSERTATION
FOR THE ATTAINMENT OF THE DEGREES
OF
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ROSTOCK: ADLER'S HEIRS.

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3.*) The system of measuring the horizontal angles between the lines of survey, and determining the bearings of one or more lines.

In consequence of the uncertainty of obtaining accuracy in surveys made by aid of the magnetic compass, it has been the aim of various scientific men to institute some system of surveying mines having but one shaft, wherein the necessity of making use of the compass is avoided. It will be as well under this head to consider firstly the mode of taking the horizontal angular measure between two lines, and so carrying on the survey; and secondly the methods to determine the bearings of lines above and underground, so as to connect the two surveys.

The instrument almost universally used by good surveyors for measuring azimuths, or angles in a horizontal plane, is the „theodolite“, which is also very useful for measuring altitudes and depressions,

*) There precede in the manuscript an introduction and two chapters viz: 1) the instruments used for measuring distances, 2) the system of determining the bearings of the lines of survey by means of the magnetic compass.

or angles in a vertical plane. The structure of the theodolite varies a good deal, but the essential parts are common to all. The „transit theodolite“, possessing greater capability and accuracy, in which the telescope can be moved round the entire circle in the vertical plane, has to a great extent, and justly, superseded the older form having a limited vertical arc. The size of the circles, both horizontal and vertical, and the minuteness of their graduations, should depend on the extent and accuracy of the operations for which they are intended. For sufficient correctness in mine surveys it is unadvisable to use a theodolite having a horizontal circle of less than five inches in diameter, divided into half-degrees, subdivided by the vernier scales to single minutes, and by estimation with the eye to half or quarter minutes; but it is considered better, to ensure greater accuracy in extensive surveys, to use one with a horizontal circle of six inches in diameter, divided to twenty minutes, sub-divided by the verniers to twenty seconds, and by estimation with the eye to ten seconds. In some theodolites a second telescope is attached below the horizontal circle, in order, by directing that telescope to an object, to test whether the circle has been disturbed during the interval between two observations, but this becomes unnecessary when for the sake of lessening errors, the observations are repeated.

Perhaps the best plan to adopt in surveying underground with the theodolite is to provide three tripod stands of convenient height, having an arrange-

ment to readily fix the instrument on them and each supplied with a suitable object mark, to be attached to the two not at the time carrying the theodolite. Marks for this purpose far superior to the lamps or lighted candles generally used by surveyors, are tubes of metal painted white, which can be easily screwed in the position where the vertical axis of the theodolite would be when fixed on the tripod; by the aid of the light of good lamps (such as those called „bull's eyes“) thrown on the marks, they may be bisected by the wires of the theodolite with great precision. The mode of procedure with the three tripod stands is as follows: — the theodolite is fixed on one of the tripods, the second is placed in the position of the back sight, with the before mentioned object mark attached to it, and the third is sent to the forward sight, also with the mark attached; the angle between the sights having been taken, and the distance between the first and second tripods measured, the back tripod is taken up and carried forward to the next station beyond the third tripod, to which latter after the object mark has been taken off, the theodolite is removed; the back and forward tripod stands having their marks attached, the observation of the angle is taken, and the survey proceeds as before. By this plan much time is saved, and all errors in fixing the theodolite stand over the position of the former forward sight, are avoided; it is as well however where possible for a chalk or other mark to be made on the roof by the aid of a

plumb line, where the tripods stand, that the stations may be returned to if necessary, this may be done by one of the assistants without loss of time.

It may, however, sometimes occur that in placing the forward tripod stand on irregular ground, the top is so much out of the horizontal, that when the theodolite is removed to it, it is found impossible to level the instrument by means of the screws. In this case, particular care must be taken that the vertical axis, or lower horizontal plate of the instrument is kept clamped during the whole operation. The apparent horizontal angle between the object marks is taken, and the altitudes or depressions of the marks are observed. The telescope of the theodolite is then turned horizontally round until the cross level on the vernier plate is level, and as in this position the cross level is evidently parallel to the bisection of the plane of the instrument and the true horizontal plane, by reading the vernier scales, the points of bisection are obtained. The telescope is moved up or down (the cross level being level) until the level attached to the telescope is perfectly level, and the reading of the vertical circle is taken; the telescope is turned horizontally round 180° , so that the cross level is again level, the process is repeated, and the mean of these readings will obviously give the error in level of the instrument. To make use of these observations, that is to say: — (Problem) — „The apparent horizontal angle between two objects having been measured by a theodolite having its horizontal

limb considerably out of level, to find the correction, having given the error of level of the instrument, and the altitudes and depressions of the objects." —

In the diagram fig. 1, let S ., Q ., be the two objects.

let $XAX'B$ be a great circle in the plane of the instrument.

$XEX'F$ a horizontal great circle, intersecting the plane of the instrument in XX' , 180° apart.

LL' the measured angle between the objects.

DD' the true angular distance required.

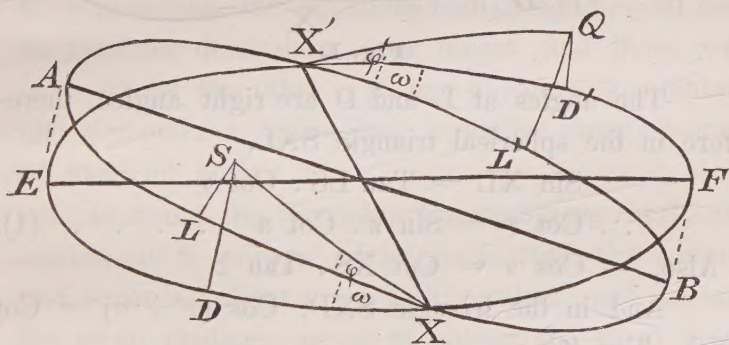


Fig. 1.

If the distances XD , XD' are determined, the required horizontal angle is easily obtained.

Firstly, to determine the true azimuth, and altitude of the object S from X .

Let $XL = z$, be the observed azimuth from X .

$LS = a$, the observed altitude from X .

$XD = Z$, the true azimuth from X .

$DS = A$, the true altitude from X .

Let the angle $DXL = \omega$, the error in level of the instrument, obtained by observation.

the angle $LXS = \varphi$.

Then the angle $SXD = \varphi + \omega$.

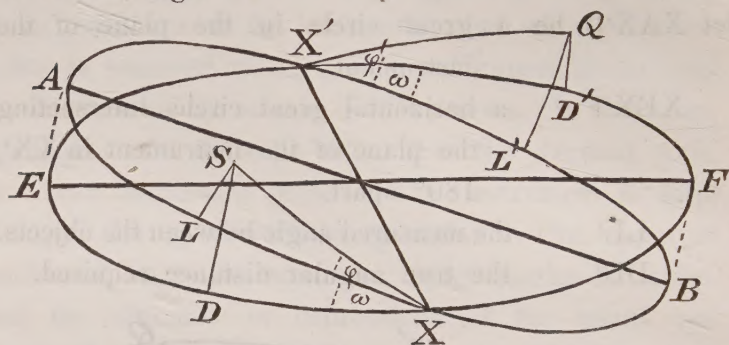


Fig. 1.

The angles at L and D are right angles, therefore in the spherical triangle SXL,

$$\sin XL = \tan LS \cdot \cot \varphi$$

$$\therefore \cot \varphi = \sin z \cdot \cot a \quad \dots \dots (1).$$

Also, — $\cos \varphi = \cot XS \cdot \tan z$.

And in the triangle SXD, $\cos (\varphi + \omega) = \cot XS \cdot \tan Z$.

$$\therefore \tan Z = \tan z \cdot \frac{\cos (\varphi + \omega)}{\cos \varphi} \quad \dots \dots (2).$$

From the equation (2) the true azimuth Z is obtained, φ being determined from the equation (1).

To obtain the true altitude, or value of A.

In the triangle SXL, $\sin a = \sin \varphi \cdot \sin XS$, and in the triangle SXD, $\sin A = \sin (\varphi + \omega) \cdot \sin XS$.

$$\therefore \sin A = \sin a \cdot \frac{\sin (\varphi + \omega)}{\sin \varphi} \quad \dots \dots (3).$$

Secondly, the true azimuth Z' and altitude A' of Q from X' are obtained by substituting $(\varphi - \omega)$ for $(\varphi + \omega)$ in the above equations,

$$\text{Tan } Z' = \text{Tan } z' \cdot \frac{\text{Cos } (\varphi' - \omega)}{\text{Cos } \varphi'} \quad . \quad . \quad . \quad (4).$$

$$\text{Sin } A' = \text{Sin } a' \cdot \frac{\text{Sin } (\varphi' - \omega)}{\text{Sin } \varphi'} \quad . \quad . \quad . \quad (5).$$

Where the value of φ is obtained from an equation

$$\text{Cot } \varphi' = \text{Sin } z' \cdot \text{Cot } a', \text{ similar to (1).}$$

z' , an a' being the observed azimuth and altitude of Q from X' .

It is obvious that if both the objects are altitudes or depressions, the equations containing $(\varphi + \omega)$ must be used for determining one object, and those with $(\varphi - \omega)$ for the other. If one object is an altitude and the other a depression, a similar equation must be used for both.

In using the theodolite for measuring horizontal angles, it is always advisable to read the minutes and seconds indicated by both verniers, and to take the mean readings, so as to correct the effect of any errors which may arise from the vertical axis not being exactly concentric with the graduated limb of the horizontal circle. In the transit theodolite, errors arising from the horizontal axis not being exactly perpendicular to the vertical axis may be eliminated by turning the telescope over about the horizontal axis, and half round about the vertical axis, repeating the measurement of the angle in this new position, and taking the mean of the results. In all cases it

is advisable to repeat an observation made with the theodolite, for mistakes which occur occasionally in reading the verniers are thereby discovered, and also the process of repetition tends to diminish errors of observation, and even graduation. In repetition it is better always to direct the telescope towards the back sight by turning the vertical axis, and towards the forward sight by turning the upper horizontal, or vernier plate; in general it is sufficient to observe an angle twice.

Other instruments for measuring angles, such as the „sextant“, and „box sextant“, are so far inferior to the theodolite for the purpose, that they are never used in mine surveys, more especially as the horizontal angles between two objects are required in surveying, and not the actual angles subtended by the objects.

Two surveys, one made aboveground, and the other underground, both by means of the theodolite, obviously have no connection, the object therefore to complete such surveys is to determine the direction of a line in each survey with respect to one another.

The system of conducting a mine survey wholly without the aid of the magnetic needle, the reference to which is the especial purport of this dissertation is the invention of Mr. Arthur Beaulands M. A., Civil Engineer, and surveyor. The practical adoption of the system by Mr. Beaulands, and myself, to whom only it is known, has met with great and unexceptional success, the extreme accuracy of the results in

some cases being truly surprising; the whole process however is one requiring great care and an intimate acquaintance with the use and manipulation of the instruments. The leading feature of the plan consists of a method of determining a bearing, or meridian line at the bottom of the shaft of a mine, the direction of which is determined either with reference to the true meridian, or to some line arbitrarily fixed on the surface. By this means both the underground and surface surveys made with a theodolite may be properly connected together, the system being alike applicable to shallow and deep mines.

The process is effected by means of a powerful transit instrument, mounted in the line of the shaft, either at the top or bottom, as may be considered most convenient, but as it has been found from experience that the top of the shaft is the better in nearly all cases, it will tend to simplicity to consider only the case of the instrument fixed at the top of the shaft, as the process is similar in both cases. The transit instrument used for the purpose differs but little from that used by astronomers; the stand is constructed of solid cast iron, with an aperture in the centre of its base, in order that the telescope may be pointed vertically downwards; in addition to the stationary wires in the principal focus, there is a moveable one, parallel to those perpendicular to the horizontal axis, motion to which is communicated by a micrometer screw; the angular value of the divisions on the micrometer it is necessary to ascertain with perfect

accuracy, in the instrument used by Mr. Beaulands these divisions were found to be equal to 0.7 of a second. Two solid beams of wood are fixed across the top of the shaft, with sufficient space between them to allow a clear and un-interrupted view through the telescope when pointed vertically downwards.

The instrument is placed on these supports, carefully levelled, by means of three screws at the base of the stand, and properly adjusted. A few planks forming a platform for the observer to stand upon are fixed altogether independent of the two beams on which the instrument is placed, so that a movement on the part of the surveyor may cause no disturbance of the transit instrument. Two marks are fixed at the bottom of the shaft as far apart as possible, and as nearly as may be in the same vertical plane as the transit instrument, so that each of them can be seen through the telescope, and appears in the centre field of view; they are made as small as will allow of them being distinctly observed through the transit instrument at the top of the pit, and are constructed of sheet metal of the form represented in



the diagram fig. 2., so that they can be bisected by the wire of the instrument with great precision. These marks are arranged at an inclination of about 45° in boxes fastened on a plank in such manner that both may be seen by a theodolite placed near the bottom of the shaft in a horizontal line with them, and at the same time by

means of reflectors they may be rendered visible through the telescope of the transit instrument by the light of a strong lamp reflected upwards.

On pointing the telescope of the transit instrument downwards, it is evident that if each of the two marks appears exactly bisected by the same wire, the horizontal line in which the marks are fixed, coincides with the vertical plane of the instrument, and is consequently parallel to the direction of the telescope when pointed horizontally. In this case therefore there are two lines one at the top of the pit represented by the optical axis of the telescope when pointed horizontally, the other, the line joining the centres of the two illuminated marks at the bottom, and the bearing of the instrument being determined, either with reference to the meridian or to some determinate line on the surface, the direction of the line of marks is ascertained at the same time.

This however is on the supposition that each of the marks is precisely bisected by the same wire of the transit instrument, a condition which is never exactly fulfilled in practice. Therefore in the case of one or both of the marks being a little out of the centre field of view, it is necessary accurately to ascertain the angular deviation of the line of marks from the vertical plane of the instrument, and thus deduce the bearing of the line of marks. To accomplish this, a number of observations are made, alternately bisecting the two marks by the moveable wire of the transit instrument, each time carefully noting

down the readings on the micrometer screw, and to counteract any errors of collimation it is advisable to reverse the instrument, and repeat the process. For the sake of avoiding confusion, it is as well in making the observations, to term the marks respectively north and south (N and S), or east and west (E and W), according as the line joining them approaches a north and south, or east and west direction, and it is necessary to note whether the one mark is to the right or left of the other when the observer is facing a particular direction.

Let it be supposed that the mean difference of the readings on the micrometer screw when the wire bisects the marks at the bottom of the shaft is taken, after, as before mentioned, the angular space through which the moveable wire of the transit instrument is carried by turning the micrometer screw through one of its divisions, has been previously precisely ascertained.



Let α = the angular value of one division
on the micrometer

δ = mean difference of the readings.

Then if we multiply the difference δ by the value of the divisions α of the micrometer screw, we shall obtain the angular distance of one mark from the plane of the instrument passing through the other.

Or in the diagram, fig. 3.

Let N represent the north mark which may be supposed to be slightly to the

Fig. 3.

right of the south mark when the observer is facing north.

Let S represent the south mark. Let PS be the vertical plane of the transit instrument, or the direction of the vertical wire passing through S .

And let PN be drawn perpendicular to PS .

Then the angular distance $PN = \alpha^\circ$.

To obtain the angular distance NS between the two marks, there is the linear distance NS , which should be carefully measured, and the depth of the pit, which latter may be ascertained with sufficient accuracy on enquiry.

Let $D =$ the depth of the shaft

$d =$ the distance NS .

(D and d being in the same suits.)

$$\text{Then } \sin (NS) = \frac{d}{D}$$

$$\text{And } NS = \sin^{-1} \frac{d}{D}.$$

But it is required to determine the angular deviation of the line NS from the plane of the instrument, or the angle NSP .

$$\sin NSP = \frac{NP}{NS} = \frac{\alpha^\circ}{\sin^{-1} \frac{d}{D}}.$$

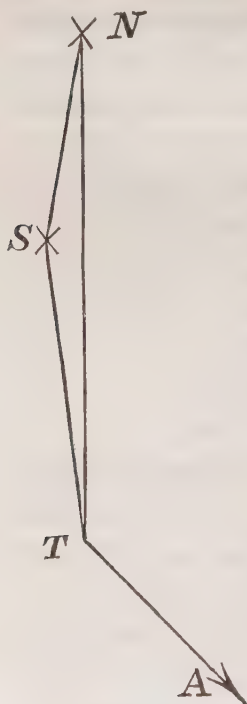
From this angle, the bearing of the transit instrument being known, the direction of the line NS joining the centres of the two marks is readily obtained.



Fig. 3.

In order to make use of the bearing

of the line joining the two marks for the underground survey, the following method is adopted. A theodolite is placed in the vicinity of the bottom of the shaft, as nearly as possible in a line with the two marks, and at a distance of from twelve to twenty feet from the nearer mark; the horizontal angle between the marks is then carefully observed. In the diagram fig. 4.



Let N represent the north mark
 S " the south mark
 T " the position of
 the theodolite.

The angle NTS is determined by observation through the theodolite. The distances NS and ST are carefully measured. Then as in small angles, the angle varies as its sine

$$\angle SNT = \angle NTS \cdot \frac{ST}{NS}$$

From the previously described observations with the transit instrument the bearing of NS is determined, therefore that of NT is readily obtained by subtracting

Fig. 4. (in this particular case, the north mark being to the right of the south mark when facing north) the angle SNT from the bearing of NS.

By observing through the theodolite at T, the horizontal angle between N and the next station A,

in the underground survey, that is the angle NTA, the bearing is carried on throughout the survey.

For the purpose of connecting the surface survey with that of the underground, it is necessary to obtain the angle aboveground, between the plane of the transit instrument, and a station in the survey. To effect this object the following plan is observed. A theodolite is placed in position aboveground at a distance of about twelve feet from the transit instrument, and as nearly as possible in the line of its plane. A lamp, or other steady light is held alternately behind the telescope of the transit instrument and that of the theodolite, and the wire of the one instrument made to coincide with the wires of the other, by observing the instrument having the light held behind it, from the other. When the wires coincide, the theodolite is obviously pointed parallel to the plane of the transit instrument. For this operation it is essential to have an eye piece of low power on the transit instrument, so that an ample quantity of light may pass through to illuminate the wires. By observing the angle between the direction in which the theodolite is by this means pointed, and a station in the surface survey the required connection of the surveys is obtained.

In some exceptional cases there is so much vapour or smoke in the shaft of a mine, that it becomes impossible to see with sufficient distinctness through the telescope of the transit instrument, the marks fixed at the bottom. Under these circumstances

it is advisable to conduct the whole of the survey by means of a theodolite, and at suitable parts of both the underground and surface surveys, to take bearings of the lines with the magnetic compass, or circumferentor, observing great care in the process, and using the same instrument throughout. If a number of these observations are taken and compared with the survey made with the theodolite, the errors arising from the use of the compass may be reduced to a very trifling inaccuracy.

A plan believed to be first suggested by Mr. Thomas Baker, civil engineer, and surveyor, for conducting a subterraneous survey entirely without the aid of the magnetic compass, is of a very simple nature, but its accuracy appears to be extremely questionable. The method is to suspend two thin copper wires carrying heavy weights, from a strong straight-edge at the top of the pit, and as near the edges of the shaft as not to touch them, the weights reaching to the bottom of the pit; the weights are immersed in buckets of water, or what is better, in vessels filled with mercury, to diminish oscillation. In deep pits however, oscillation will be almost constant, and unavoidable, and hence arises a cause of material inaccuracy in the system. Underground, from the bottom of the shaft some one proceeds with a lighted candle as far as can be seen from the wires, and the surveyor standing behind the wires, directs the holder of the candle, and has it fixed in a line with the wires. This operation is repeated where possible in

the opposite direction, so that by placing a candle against one of the wires, the whole may be checked by seeing that the three candles are exactly in a line. This line being the basis of the whole underground survey, is permanently marked by four or more pegs with nails in them, driven into the roof, or by marks on cross timbers or masonry. At the surface the same process is gone through, using poles, or other suitable marks instead of candles, and permanent pegs are placed at some chains' distance on each side of the shaft, in a line with the wires. A line is thus obtained on the surface corresponding in direction with the base line of operation underground. With these lines the surface survey and that of the underground are connected.

This method of connecting the two surveys is obviously open to serious objections, when an extensive survey is to be made, for without the aid of a telescope it is almost impossible to determine with the eye, a sufficiently accurate continuation of the line of wires, and underground in addition to the difficulties arising from the constant oscillation of the wires, the space for setting out the line is generally so limited, that the line can possibly be set out only on one side of the shaft, and on that side to a very short distance.

The systems above described of connecting the surface survey with that of the underground are used in the event of there being only one shaft to the mine required to be surveyed. Should there be two

shafts at some distance from each other, it is hardly necessary to make use of either of the systems, as there are then two points (such as the centres of the shafts) in the survey, in the same position above and underground, and if these points coincide, the two surveys are evidently correctly connected*).

*) There is yet following in the manuscript a fourth chapter:
 „The methods of plotting a survey on paper.“